R-390A Noise Limiter filament current reduction resistor

Larry Haney, 7-11-2020

I have never been quite sure what the purpose was for the dropping resistor in the limiter filament circuit, so I did some research on this question for another forum post and discovered it is to reduce hum in the audio. When a noise limiter filament dropping resistor is used, it reduces a low level of hum in the noise limiter circuit, which would have been fed into the audio. This has to do with the way tubes work. Of course, I missed David Wise's post about this on Apr 29, 2009 until just a few days ago. It's included a little later.

Here's the post in antiqueradios.com/forums/ for those interested. To explain diode tube operation, Ed Engelken wrote this in this forum post following Avery's post:

Post subject: Filament-dropping resistor in NC-183
Posted: Jan Sun 06, 2013 2:11 pm
A puzzler (maybe not to Carl): Checking out a National NC-183 after a friend's recap, I see a 4.3 ohm resistor in the filament line supplying V10, the 6H6 limiter. Looks like an original, probably 2 watts with characteristic slightly rough exterior. No such value in the parts list. Measures 4.5 ohms, not bad after 50 years!
But why is it there? It's the only tube with a dropping resistor in the filament line.
Avery W3AVE
Post subject: Re: Filament-dropping resistor in NC-183
Posted Jan Sun 06, 2013 2:43 pm
Lowering the cathode temperature in a vacuum tube diode reduces the contact bias that occurs when electrons emitted from the cathode contact the plate. That bias must be overcome before rectification can take place. The effect of contact bias in a vacuum tube diode is similar to the forward drop in a silicon diode.
Both National and Hallicrafters used filament dropping resistors in the 4 to 7 ohm range for the 6H6 and 6AL5 tubes used for detectors and noise limiters in many of their receivers.
Ed Engelken

Although, Ed explains what goes on in a tube, he does not explain what that does to the circuit. The reason is further explained in this post in the AMFone blog on this subject. In this thread, k4kyv (Don) asks why is there a resistor in the filament line of the limiter in my 75A4? W3JN (John) replies with: "That's typical with detector circuits as well; many Hallicrafters and National 6H6s, 6AL5s, etc use this arrangement.. Reduces the contact potential of the diode, and **decreases hum in small signal circuits**." And, AB2EZ (Stu) responds with a much more detailed and indepth explanation of the tube operation. The first 4 entries in this thread are very worth while reading.

For those interested, here's the 4 posts in amfone.net/Amforum/ . My appologies for not including the date and time of these posts, but they are not listed and I do not know how to get them:
k4kyv:
I was looking over the schematic of my 75A-4, and noticed that V-12, the 6AL5 dual diode noise limiter has a 10-ohm resistor in series with pin #4 which goes to the filament. The voltage/resistance chart lists the normal voltage on that pin as 4.3 volts instead of 6.3. The other side of the filament is grounded.
Does anyone know why Collins might have reduced the filament voltage to that tube? In the circuit description there is no mention of what purpose this is supposed to serve.
Don
w3jn:
That's typical with detector circuits as well; many Hallicrafters and National 6H6s, 6AL5s, etc use this arrangement.. Reduces the contact potential of the diode, and decreases hum in small signal circuits.
John
AB2EZ:
I was thinking about this on the train ride into work today.
I would assume that JN has a lot more background on this... so consider my (alternative) answer as just a guess based on the physics of the vacuum tube diode:
Bottom line: my guess is that by lowering the filament voltage (and therefore the cathode temperature) the Collins

folks were attempting to introduce an offset in the turn-on voltage of the diode. I.e., to make it turn on at some positive plate-to-cathode voltage that is higher than zero. Of course, there are other ways to introduce an offset in the plate-to-cathode turn-on voltage (e.g., apply a reverse bias through a sufficiently high impedance)... but those approaches had their own engineering challenges back then (circa 1955).
More details:
In order for an electron to leave the surface of the cathode (i.e., to overcome the surface "work function") it must have a sufficiently high velocity in the direction perpendicular to the surface.
At room temperature (no filament voltage) the average thermal energy of the electrons is such that it is extremely unlikely* that an electron would have enough kinetic energy to overcome the "work function"... and thus leave the surface of the cathode.

[*The electrons have a statistical distribution of thermal energies... so some have more than the average thermal energy and some have less. The statistical distribution is known as the Boltzmann distribution.]
At full filament voltage, the temperature of the cathode is sufficient to produce a high enough average thermal energy of the electrons... such that a significant fraction of the electrons have enough kinetic energy to overcome the "work function" and leave the surface of the cathode. With no plate-to-cathode voltage applied, they form a cloud of electrons near the cathode. When positive plate-to-cathode voltage is applied, these liberated (from the surface of the cathode) electrons will flow toward the plate... producing the forward current.
With reduced filament voltage, the temperature of the cathode is not sufficient to produce a high enough average thermal energy among the electrons... such as to cause a significant number of electrons to be liberated from the surface of the cathode... and available to produce a current when the plate is slightly positive with respect to the cathode.
However, at this reduced filament voltage, the temperature of the cathode is high enough so that a combination of their thermal energy and the potential energy associated with a high enough electric field (near the cathode) will cause electrons to leave the cathode and flow to the plate.
This field, near the cathode, can be produced by the application of a sufficiently high plate to cathode voltage. [I.e., the field strength is roughly equal to the plate-to-cathode voltage divided by the distance from the plate to the cathode]
Thus, by reducing the filament voltage, the diode will not conduct until the applied plate to cathode voltage is above a certain threshold.
Stu
w3jn:
You're pretty much on target, Stu. The effetcive contact potential between the cathode and plate is also affected by the space charge. Reducing the cathode temperature reduces the space charge thereby affecting the effective contact potential. Or so I understand it from my nuclear physics class from 25 years ago.
John

John (W3JN) found the actual information on reducing hum documented in the Hallicrafters R-274 manual TM 11-897 on page 49 under power supply. A Hallicrafters R-274 is similar to a Hallicrafters sx-73. Here's the relavant information that it says: "Tubes V12 and V16 are important from the standpoint of hum in the audio amplifier. Hum can be reduced by reducing the heater voltage of a tube. Therefore, the voltage on heaters of V12 and V16 is reduced by resistor R105 to approximately 5.5 volts." V12 is a 6AL5 and is the audio detector and noise limiter, V16 is a 6AT6 and is the 1st audio amp.

Here's my understanding of how the full filament current and higher cathode temperature (no filament dropping resistor used) causes a low level of hum in the tube noise limiter circuit. Even with no plate voltage applied to the limiter (cathode to plate equals zero volts), there is still a very small amount of current flowing to the plate. Because the filament is being heated by an AC current, the electron cloud on the cathode (which causes this small current flow) is fluctuating at that frequency, so the very small current flow to the plate is also fluctuating at that frequency, 60 cycles. Hence, we have AC hum in the limiter plate circuit. This, of course, will go directly to the audio input. Normally we will not notice the hum because there is usually sufficient audio signal level to obscure it (an audio signal equals voltage on the Noise Limiter plate). But, when there is no or very low audio, then it is noticeable. This situation happens often enough that it is a problem.

Today we do not see that many resistors in the detector diode filament lines. I believe this is because the RF output of the IF amplifier is high enough that there never is zero signal input to the detector. In order for the hum to be there, it needs to have no or close to it input.

The following post was made on our R390 List Forum in 2009:
David Wise, David_Wise at Phoenix.com, Wed Apr 29 13:19:46 EDT 2009
The limiter is running dim to reduce noise and hum.
Those cathodes are at the input of the audio chain, and they're floating around at high impedance; the slightest H-K leakage would cause hum. In some positions in old tube-type Tektronix oscilloscopes, a tube might be selected for low leakage. The other day I noticed hum in my R-390A when the limiter was on. I replaced the limiter tube and the hum stopped. The original tube did not register any leakage on my Hickok 600A.
Tube audio preamps run dim to reduce noise. If the cathode emits enough electrons to satisfy the maximum requirement of the circuit, then it's bright enough. The requirement here is very small.
Dave Wise

There are many other tubes used in limiter and detector circuits in many other receivers.

I thought I'd check and see how many receivers use them today or what else they use. I knew that the R-390A uses 5814/12AU7 dual triodes connected in a diode configuration (the grid tied directly to the plate). Well, to my surprise, I find that the 51J-3 (R388) and 51J-4 use a 12AX7 (dual triode) for the audio and avc detectors and 1/2 of a 12AX7 for the noise limiter. These are of course connected in the diode configuration as just described. And, guess what, only the half of the 12AX7 used for the noise limiter has the filament dropping resistor. The Hallicrafters SX-111A uses a 6BJ7 (triple diode) for audio and avc detectors and the ANL, and uses a filament dropping resistor in it's line. The 75A4 uses four 6AL5s for a few functions and one is for the noise limiter (V12), and it is the only tube that has a filament dropping resistor. The other three 6AL5s (V10, V16, and V19) do NOT. The Hammarlund HQ-100A has the dropping resistor in it's noise limiter tube, a 6BV8.

The R390 and R391 have a similar design to the R-390A for the limiter filaments – both 12AU7 tubes have a resistor in parallel with the half of the dual triode filament used as the limiter and a resistor in series with both filaments. The R392 does not need a dropping resistor because the filament is supplied with DC voltage.

You can see from the above that at least four different tube types (besides the 6H6 and 6AL5) are used in noise limiter circuits that use the filament dropping resistor. I had no idea that this practice was so wide spread, but now I know why.